tial be realized. Second, there are problems of reorganizing the observatory to operate in a wholly changed political environment. Under the Soviet system, Borovoye was a major project of the All-Union Academy of Sciences, doing work of interest, for example, to the Soviet Ministry of Atomic Energy and Power. But in 1992 there is no central system of Soviet support, and the relationship between Kazakhstan and Russia is not always hospitable to a field station formerly operated from Moscow. Station operations were cut back in March 1992, with several sesimometer recording systems turned off due to lack of funding for the necessary staff, and/or to lack of recording tape.

Yet there are important roles for Borovoye still to play. The archive is an irreplaceable data base on the seismicity of central Asia, and any serious attempt to work on seismic hazard of Kazakhstan and neighboring states must recognize the importance of preserving both the archive and the community that can use it at Borovoye.

At the international level, the United States has a common interest with Russia and Kazakhstan in preserving and strengthening the Non-Proliferation Treaty. The technical challenge in monitoring treaty compliance into the future includes the need to monitor for nuclear explosions in all possible types of geological environment. The country with the greatest experience in executing nuclear explosions under different shot-point conditions is the former U.S.S.R., with its several nuclear weapons test sites and a program of "peaceful nuclear explosions" carried out for various purposes at about one hundred different locations across a wide range of geological conditions [*Scheimer and Borg*, 1984; *Sykes and Ruggi*, 1989]. Here too, Borovoye represents an important data base and expertise that could assist in international plans for continuing the nonproliferation regime.

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References

Adushkin, V. V., and V. A. An, Seismic observations and monitoring of underground nuclear explosions at Borovoye Geophysical Observatory, *Izv. Acad. Sci. USSR Phys. Solid Earth*, *1023–31*, no. 12, 1990.
Given, H., U.S./U.S.S.R. seismological network developing, *Eos Trans. AGU*, *72*, 112, 1991.
Kedrov, O. K., and V. M. Ovtchinnikov, An on-line analysis system for three-component seismic data: Method and preliminary results, *Bull. Seismol. Soc. Am.*, *80B*, 2053, 1990.
Landers, T., Some interesting central Asian events on the Ms: mb diagram, *Geophys. J. R. Astron. Soc.*, *31*, 329, 1972.
Scheimer, J. F., and I. Y. Borg, Deep seismic sounding with nuclear explosives in the Soviet Union, *Science*, *226*, 787, 1984.
Sykes, L. R., and S. Ruggi, Soviet nuclear testing, in *Nuclear Weapons Databook*, vol. 4, *Soviet Nuclear Weapons*, edited by T. B. Cochran, W. A. Arkin, R. S. Norris, and J. Sands, pp. 332–382, Ballinger, Cambridge, Mass., 1989.

Space Station Survives Vote

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On April 29 the House of Representatives defeated an amendment to terminate Space Station Freedom. The vote was on an amendment offered by Rep. Tim Roemer (D-Indiana) to H.R. 4364, the Fiscal Year 1993–1995 NASA authorization bill. The amendment lost by a vote of 159–254.

This is not the last vote the House of Representatives will have on the space station, nor is it the most important. Rep. Bob Traxler (D-Michigan), an opponent of station funding, argued that this was not the right way of dealing with the issue (calling it "a paper tiger"), and voted against Roemer's amendment.

The House Science, Space, and Technology Committee followed an unusual approach in writing this authorization bill. Under this legislation, $14.3 billion is authorized (permission granted to spend) in the core section of the bill. This is a freeze on money for a "balanced science program," space station, and other ongoing programs. An additional $952.1 million is authorized for "special initiatives," but only after money for the core programs is first appropriated. Earth Observing System funding is contained in this second title of the bill.

Rep. Ralph Hall (D-Texas) explained during House debate that the committee views the space station as "central" to the "interdependent" NASA programs in the core section of the bill. Referencing the impact which space station funding has on other programs, Hall contended that "the space station does not compete with any other nonspace expenditure such as the super collider, housing, veterans, and on and on." Station opponents took strong issue with this position; Rep. Howard Wolpe (D-Michigan) warned that station funding is "gutting space science programs," citing CRAF, and possibly Cassini funding next year.

Despite much discussion about the coming budget crunch, concern about big science funding impacts, and a host of other budget-related problems, the space station survived another attempt at eliminating it from NASA's budget. As Traxler declared, "the real up or down vote on station is going to come on the appropriation bill." Space station supporters have to be encouraged by last night's vote, with station opponents having their best chance at derailing the program in the upcoming (May or June) vote on the appropriations bill for the VA, HUD, and Independent Agencies.—*Richard M. Jones, American Institute of Physics*

NADW Formation as a Branch of the Hydrological Cycle

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The wide interest in the nature and evolution of deep ocean circulation as a key factor to understanding climate change set the stage for a conference devoted to North Atlantic Deep Water (NADW) formation held at Lamont-Doherty Geological Observatory (LDGO), Palisades, N.Y., from November 11 to 12, 1991. Sponsored by the LDGO Climate Center and hosted by Wally Broecker, about seventy scientists attended. Twenty-seven invited papers were presented at the 2-day conference.

The rates and paths of NADW formation were the focus of the first day. Bob Dickson, Lowestoft, U.K., summarized the present state of the "northern end" of global thermohaline circulation. In contrast to the view one obtains from many existing numerical models, especially the simpler ones, NADW derives, in reality, from a mixture of distinctly different water masses before it spreads into the world ocean. At most, 50% of the estimated 20 Sv (1 sverdrup = 10^6 m^3/s) of North Atlantic overturning actually comes from the Arctic via the overflows east and west of Iceland; the rest is thought of as recirculating water from the Labrador Sea. The Greenland-Iceland ridge overflow conspicuously lacks both seasonal and interannual variability in the transport. This is an important constraint for future modeling efforts.

Radiocarbon measurements suggest that the ventilation rate of NADW has averaged 20 Sv over the last few hundred years (Broecker, LDGO). Current meter results summarized by Dickson give a value of about 5 Sv of new water, and 12 Sv including recirculation. While it is encouraging that these diverse approaches give similar numbers, it must be determined whether the difference is carrying an important message. If the difference between the measured and the rates inferred from radiocarbon can be attributed to entrainment, consistency requires that the entrained water must also have exchanged radiocarbon through contact with the atmosphere.

Freon data from the western boundary current flowing at a depth of 3500 m along the continental margin of North America contains a sizeable component of water that was in contact with the atmosphere no more than 20 years ago (Smethie, LDGO). Tritium, helium-3, and freon data from the deep Greenland Sea demonstrate a near cessation in deep ventilation during the 1980's (Schlosser, LDGO). Yet, both current meter and western boundary current freon data suggest no interruption of NADW formation. Does this mean that the Greenland Sea window is not a key part of the NADW formation process, or that the downstream system is buffered against lapses in deep water production in the Greenland Sea?

Several contributions focused on the present state of deep circulation: interannual variability (Levitus, NOAA/NODC), the precise definition of freshwater fluxes for a global budget (Schmitt, WHOI), and the puzzle of the absence of variability in spite of the relatively short renewal time in the Arctic (Aagard, NOAA).

Ed Boyle (MIT) reviewed ocean climate during the last glacial maximum as obtained from a multiple-tracer analysis. The glacial state of the North Atlantic can be characterized by somewhat shallower NADW (low in nutrient content), underridden by a strong flow of Antarctic-derived bottom water (high in nutrient content). The ventilation rate of the global ocean was not much different from today. Heat release to the northern Atlantic that is so important to today's climate in Europe was cut way back during glacial time; however, NADW formation was reduced by, at most, 50%. The carbon isotope and cadmium data seem to exclude complete reversals of the Atlantic thermohaline circulation. Some ocean and climate models, on the other hand, suggest jumps from one mode of circulation to another. These still appear to be a plausible process for explaining the rapid transitions observed in the Greenland ice core record.

The data also reveal a subtle interaction between the location of meltwater discharge during the end of the last glacial and the position of the polar front. Its location determines whether the fresh water can penetrate the higher latitudes of the North Atlantic, where it may disturb NADW formation, or whether the meltwater is simply recirculated at lower latitudes.

The following papers concentrated on relatively short-term climatic variability of the deep-sea record (order 100–1000 years). A time series of calcium carbonate in a Bermuda Rise core suggests that the North Atlantic underwent several transitions from one state of operation to another in accord with the Greenland ice core record (Keigwin, WHOI). The time during the transition to the present interglacial shows some of the large deviations in the climatic record. Coinciding in time with the meltwater pulses from the Laurentide ice sheet (Fairbanks, LDGO), these climatic events are likely due to the same mechanism. Younger Dryas would thus not stand out as a single event, but rather would be the last of a series of climatic oscillations (Lehman, WHOI; Broecker, LDGO). The pressing questions therefore arise: What is the mechanism driving these fluctuations? What is the relative importance of ocean, ice, and atmosphere? And, why did these oscillations end abruptly at the close of the Younger Dryas?

The second day of the conference was dedicated to the modeling of NADW formation. Jürgen Willebrand (IMK, Kiel, FRG) summarized the efforts made to understand its nature and variability using simple models. Most climatic application ocean models use mixed boundary conditions to account for the strong local feedback between sea-surface temperature anomalies and heat fluxes and the independence of freshwater fluxes on surface salinity. While this enables the models to exhibit different modes of circulation under identical forcing, internal variability and abrupt transitions from one mode to the other, these surface conditions are still unsatisfactory in fully explaining the climate system. Responses that the ocean experiences from the atmosphere due to anomalies are nonlocal. Such nonlocality is present in coupled models, or else must be analytically included in ocean-only models. More realistic surface flux formulations may remove the extreme sensitivity to perturbations observed in most of the present models that seem to be at odds with what the paleoclimatic record of the last 8000 years tells us.

It is clear that freshwater fluxes in the atmosphere can trigger major rearrangements of the ocean circulation. Using sea-surface temperature as the only information about the ocean, atmospheric GCMs consistently simulate the evaporation excess of the Atlantic that is responsible for the maintenance of the conveyor belt (Zaucker, LDGO). A zonally averaged ocean model elucidating the sensitivity of freshwater fluxes in the global ocean was presented by Wright (BIO, Dartmouth, Canada), and Stocker (LDGO) showed its extension toward a coupled climate model. The latter model and a box model (Huang, WHOI) indicate the importance of the atmosphere in determining the rates and structure of NADW formation. The modeling of meridional fluxes in ocean GCMs was revisited by Bryan (GFDL), giving little hope for higher-resolution versions to shed more light on the outstanding problems. Stommel (WHOI) explained a fundamental mechanism for the self-regulation of the temperature and salinity structure with latitude; Luyten (WHOI) reconstructed sources of NADW.

The final part of the conference focused on three-dimensional model results. Ernst Maier-Reimer (MPI, Hamburg, FRG) demonstrated that random freshwater fluxes at the ocean surface (simulating precipitation) can cause long-term fluctuations with characteristic periods in the thermohaline circulation. The role of wind stress in determining the outflow of the Atlantic into the Southern Ocean was examined by Toggweiler (GFDL) and represents a mechanism (though external to an ocean-only model) to significantly modify the deep circulation in the Atlantic. Marotzke (MIT) demonstrated different stable equilibria in an ocean GCM, in particular, two possible states of the conveyor belt. However, neither mode has intermediate instead of deep water formation in the Atlantic, and therefore may not represent glacial and interglacial "conveyor" modes.

In a highly idealized geometry of a hemispheric box ocean, internal decadal variability can be present (Weaver, Montreal, Canada). Using a computer-efficient diagnostic model, Sarachik (Seattle) indicates that deep circulation may be more stable and exhibit strong self-sustained oscillations on the millenial time scale. Gyre circulation and Ekman overturning are important mechanisms for stabilization. This is somewhat in contrast to the high sensitivity in the coupled atmosphere-ocean GCM at GFDL (Stouffer, GFDL) where major reorganizations are completed within less than 100 years. Finally, Manabe (GFDL) presents a thermal feedback mechanism that may render the coupled model less sensitive to perturbations such as anomalous runoff.

Thus, these major puzzles must be attacked in future studies:

- The paleoclimatic records must decide how, when, and where changes of NADW formation occurred and what the history of the "blend NADW" was.
- The extreme sensitivity of numerical models must be reconciled with the apparent stability of global conditions during the last 8000 years, which may be achieved by a better formulation of surface boundary conditions and parameterization of deep water formation.
- The simplest set of mechanisms necessary in explaining the climate record must be determined, in particular, the high degree of variability during the glacial and the relative lack of it in the present interglacial.

One of the purposes of the conference was to bring researchers concerned with the reconstruction of past climatic changes together with those modeling them. It is clear that for a fruitful and continuing interaction between these two approaches, modelers will have to focus more on key geographical areas or find appropriate parameterizations, and results from climatic reconstructions will have to fit into a more global perspective.—*Thomas F. Stocker and Wallace S. Broecker, Lamont-Doherty Geological Observatory, Palisades, N.Y.*

FORUM

A Forum for the Teaching of Geophysics

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Here is a proposal for an experimental publication in an area new to AGU.

AGU currently has five core publications: *Eos* communicates within the scientific community; *Journal of Geophysical Research* (all colors and hues) and *Water Resources Research* are the mainline archival journals; *Geophysical Research Letters* features quick, short, and timely publications; and *Reviews of Geophysics* integrates current research into coherent overviews. Nowhere does the Union offer a forum for the teaching of geophysics similar in scope to the *American Journal of Physics*, which, unfortunately, does not cover our territory.

Quite a few AGU members have developed materials for use in university courses on geophysics or in self-study by working scientists, yet no easy way exists for sharing them. For instance, while teaching a course, one member developed a laboratory model of the Earth constructed from a bowling ball. The ball was filled with fluid and equipped with transducers, and when it was hit with a